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MODEL STUDY OF NARRAGANSETT BAY

EFFECTS OF FOX POINT BARRIER ON WATER TEMPERATURES

INTERIM REPORT 3

September 1959

U. S. Army Engineer Waterways Experiment Station
CORPS OF ENGINEERS
Vicksburg, Mississippi

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Preface

The tests described in this report were performed by the U. S. Army Engineer Waterways Experiment Station in compliance with a request from the U. S. Army Engineer Division, New England, contained in first indorsement of 1 April 1959 to basic letter dated 27 February 1959, subject: Proposed Temperature Studies in Existing Narragansett Bay Model. The tests were made in May and June 1959.

Engineers of the Hydraulics Division, Waterways Experiment Station, actively connected with the study were Messrs. E. P. Fortson, Jr., Chief, Hydraulics Division; G. B. Fenwick, Chief, Rivers and Harbors Branch; H. B. Simmons, Chief, Estuaries Section; and W. H. Bobb, project engineer, who was assisted by E. B. Jenkins, H. R. Smith, and O. H. Rhodes. This report was prepared by Messrs. Simmons and Bobb.

Director of the Waterways Experiment Station during the performance of the tests and preparation of this report was Col. Edmund H. Lang, CE. Technical Director was Mr. J. B. Tiffany.

Contents

Model Study of Narragansett Bay

Effects of Fox Point Barrier on Water Temperatures

Interim Report 3

Introduction

1. Construction of a barrier across the Providence River in the vicinity of Fox Point was recently authorized by Congress to protect a large portion of downtown Providence, Rhode Island, from flooding by the extreme tides associated with tropical hurricanes which strike the New England coast in the vicinity of Narragansett Bay. The barrier will be equipped with sluice gates of adequate size and design to maintain the existing tidal prism upstream from the barrier site. However, it was considered possible that changes in current patterns and vertical mixing caused by the barrier might result in increases in water temperature upstream from the structure where the Narragansett Electric Company operates two power generating stations (the South St. and Manchester St. Stations) which draw condenser cooling water from the Providence River. The problem area is shown in plate 1, and the locations of the barrier and the intake and outlet works for the cooling water are shown in plate 2.

2. The tests reported herein were conducted to determine the effects of the barrier on water temperatures upstream from the structure for average conditions of tide and fresh-water discharge. No attempt was made to determine the extreme seasonal fluctuations in water temperature, either without or with the barrier installed in the model, since it was contemplated that other provisions would be made for the necessary supply of cooling water if the results of tests for average conditions indicated a significant increase in water temperature.

The Model

3. The tests were conducted in the comprehensive model of Narragansett Bay. A description of the model, as well as the details of its adjustment and verification, is presented in interim reports of

February 1957 and June 1959, and is not repeated in this report. Since the model was designed and operated in accordance with the Froudian scale relations, a temperature scale of 1:1 was applicable for the tests.

Test Technique

4. Water temperature in the Providence River is affected by many factors other than the circulation of cooling water, the most important of which are probably the air-water temperature difference and evaporation. Since these two factors could not be reproduced in a quantitative manner in the existing model, and since only the effects of the cooling water circulation, without and with the barrier, were to be studied, it was necessary to develop a technique whereby the effects of cooling water circulation and the barrier could be isolated by holding all other factors constant.

5. During the course of some exploratory tests, in which the circulation of the cooling water was not simulated in the model, it was noted that the temperature of the model water varied by as much as 3 F over the period of time considered to be necessary for the subsequent temperature tests. It was therefore necessary that some means of correcting for the effects of hourly and daily temperature differences be devised, so that the effects of the barrier and cooling water circulation during the course of a test, and also from test to test, could be isolated. A correlation between the rate of change in air temperature and water temperature was first attempted, but it was soon found that short-term changes in the rate of evaporation of the model water, which in turn affected the model water temperature, made such a correlation impossible.

6. From water-temperature measurements made throughout the model during the exploratory tests, it was noted that a constant relation existed between the temperatures measured throughout the Providence River problem area and that of the fresh water discharged into the Woonasquatucket and Seekonk Rivers. The factors which resulted in short-term changes in water temperature throughout the problem area produced equal changes in the temperature of the fresh water, and since the circulation of cooling water could not affect in any way the temperature of the fresh

water, it was decided that the fresh-water temperature would serve as a satisfactory basis for correcting for all effects other than those attributable to the barrier and cooling water circulation. All temperature data presented in this report are therefore expressed in terms of differences, either plus or minus, from the temperature of the fresh water.

Test Procedure

7. A mean tide range of 3.6 ft at Newport was reproduced for all tests, and the salinity of the model ocean was maintained at 33.0 parts per thousand. Average fresh-water discharges were reproduced in all major tributaries; these discharges were 700 cfs in the Pawtuxet River, 400 cfs in the Woonasquatucket and Moshasuck Rivers combined, 1500 cfs in the Seekonk River, and 1400 cfs in the Taunton River. The model was operated for 30 tidal cycles before circulation of cooling water was undertaken, to insure that salinity conditions were stable when circulation was started. To simulate the effects of circulation of cooling water, the proper volumes of water were pumped from the model at the respective intake locations and depths, heated to effect the average temperature increase observed in the prototype, then returned to the model at the respective outfall locations and depths. In each test, operation was continued until periodic measurements showed that no further changes in temperature were taking place throughout the problem area for the conditions of the test.

8. In the prototype, cooling water for the Manchester St. generating station is obtained through one intake and discharged through two outfalls, while that at the South St. Station is obtained through two intakes and discharged through one outfall. In the model, one intake and one outfall were provided for each generating station as indicated in plate 2. The intakes and outfalls were positioned at the proper depths so that cooling water was drawn from and released into the same strata in both model and prototype.

9. Thermometers were installed in both intake lines, and the minimum and maximum temperatures were observed during each tidal cycle after circulation of cooling water was begun. The minimum and maximum values were averaged to obtain an approximation of the mean temperature, which was

used as a basis for adjusting the temperatures of two hot-water baths through which the intake water passed in a coil before being returned to the river. The hot-water baths were adjusted to effect a 10 F rise over intake temperature for the Manchester St. Station and a 15 F rise over intake temperature for the South St. Station. The quantities circulated were 455 cfs for the Manchester St. Station and 440 cfs for the South St. Station. All tests were continued for 50 tidal cycles after the circulation of cooling water was begun, even though temperatures were essentially stable at all observation stations after about 30 tidal cycles.

10. In addition to temperature measurements in the intakes, maximum and minimum temperatures at surface and bottom were measured at stations B and G (plate 2) at intervals of 5 tidal cycles throughout each test. Running plots of these measurements and those in the intakes were maintained as an index to the time of temperature stabilization in the problem area. The temperature of the fresh water was measured at close intervals for reference purposes. Near the end of each test, when it was certain that temperatures were stable throughout the area, temperatures were measured at half-hourly intervals over a complete tidal cycle in both intakes, at the surface above both intake locations, and at surface and bottom at stations A, B, G, and 19 (plate 2). On completion of tidal cycle 50, blocks shaped to fit the channel were inserted at the two locations shown in plate 2 at the time of high-water slack of the current at the barrier site, the circulation of cooling water was stopped, the water between the blocks was mixed quickly and thoroughly, and an average temperature measurement for the entire area was obtained. It was considered that this latter procedure would provide an absolute measure of the effects of the barrier on the average water temperature upstream from the structure, whereas values derived by averaging point measurements at a number of locations might not yield an absolute value.

Conditions Tested

11. The three conditions tested in the model were the existing condition (i.e., with water drawn into and discharged from the power stations), referred to hereinafter as the base test, and plans 1 and 2. Both plans

incorporated three 40-ft-wide sluice gates, having sill elevations of -15 ft msl. For plan 1, the sluice gates were located near the east bank of the river (plate 2), while for plan 2 the gates were located to the west of the center of the river. Operating conditions for the three tests were identical and as shown in the following tabulation:

Generating Station	Intake Sill El*	Intake Height ft	Outfall Sill El*	Outfall Height ft	Cooling Water Circulation cfs	Cooling Water Temp Rise, °F
South St.	-25.5	12.0	-12	10.0	440	15
Manchester St.	-15	7.5	-4.5	7.0	455	10

* Elevations are in feet below msl. Locations of intakes and outfalls are shown in plate 2.

Results

12. The results of the tests are presented in tables 1 and 2 and in plates 3-12. Plates 3-6 show the results of periodic measurements of maximum and minimum temperatures in the two intakes and at surface and bottom at stations B and G for the duration of the base test and the two plan tests. As described in paragraph 6, temperatures for both the base test and the plan tests are expressed as differences from the fresh-water temperature; therefore, the temperature differences between base test and plan indicate directly the effects of the plan on temperatures at the point of measurement. At the South St. intake (plate 3), plan 1 caused an increase in maximum temperature of about 2.5 F at the time of stabilization, while the minimum temperature was increased about 1.5 F. At this location, plan 2 caused an increase in maximum temperature of about 1.5 F, while the minimum temperature was not changed appreciably.

13. At the Manchester St. intake (plate 4), both plans 1 and 2 caused significant increases in maximum and minimum temperatures. The increase in maximum temperature for plan 1 was about 5.0 F and that for plan 2 was about 7.0 F, while the increase in minimum temperature for both plans 1 and 2 was about 6.0 F. Increases in maximum and minimum temperatures at surface and bottom were also observed at stations B and G for both plans (plates 5 and 6); the increases ranged from about 0.5 F to about 7.0 F.

14. Plates 7 and 8 show the effects of plans 1 and 2 on temperatures

throughout a tidal cycle, after stability had been attained, at the South St. and Manchester St. intakes, respectively. Plates 9-12 present similar data for surface and bottom for stations A, B, G, and 19, respectively. Data presented on these plates indicate that, in some instances (Station A bottom, for example), the average temperature was increased more than was the maximum or the minimum temperature.

15. The effects of both plans on maximum and minimum temperatures at all observation stations are summarized in table 1, and the effects on average temperature over a tidal cycle at the time of stability are summarized in table 2. The measurements obtained after thorough mixing of the water in the problem area (described in paragraph 10) are presented at the end of table 2. These latter measurements are considered to be a reliable index to the effects of the two plans on the average water temperature in the problem area, and it will be noted that increases of 3.0 F for plan 1 and 3.4 F for plan 2 were indicated.

Discussion of Results

16. The results of the model tests indicate that the Fox Point barrier would reduce vertical circulation between that portion of the Providence River downstream from the structure and that upstream where the cooling water intakes and outlets are located, and the reduced vertical circulation would cause an increase in the average water temperature of the upstream area by 3.0 F to 3.5 F. The tests also indicate that the temperature of the intake water at the South St. Station would be increased by less than the average, and that at the Manchester St. Station would be increased by more than the average. This difference is attributed to the fact that the South St. intake is appreciably deeper than the Manchester St. intake, which lessens the effects of the reduced circulation.

17. The tests also indicate that the reduced vertical circulation would cause a slight reduction in water temperature downstream from the barrier, as evidenced by temperature measurements at station 19. It therefore follows that any scheme for drawing cooling water from the downstream area would provide cooler water to the plants with the barrier installed than would be available without the structure.

18. While not entirely pertinent to the purpose of the model tests, data obtained during the exploratory tests and the base tests indicate that the present circulation of cooling water has an appreciable effect on water temperatures throughout the problem area. During the exploratory tests, which did not simulate circulation of cooling water, it was found that the average water temperature in the problem area was 1.0 F less than the fresh-water temperature. In the base test, which simulated the existing circulation, the average temperature was 4.2 F higher than the fresh-water temperature, or an increase in average temperature of about 5.2 F because of the circulation of water at the power stations.

Table 1

Effect of Fox Point Barriers on Temperature Extremes

Location		Temp Extreme	Temperature Differences, °F				
			Base Test*	Plan 1*	Effect of Plan 1	Plan 2*	Effect of Plan 2
South St. intake		Max	-0.5	1.9	2.4	1.3	1.8
		Min	-0.5	1.0	1.5	-0.2	0.3
Manchester St. intake		Max	8.8	14.1	5.3	15.9	7.1
		Min	-0.5	5.4	5.9	5.8	6.3
Station B:	Surface	Max	10.8	17.2	6.4	17.7	6.9
		Min	2.0	3.6	1.6	3.8	1.8
	Bottom	Max	-0.8	2.0	2.8	1.8	2.6
		Min	-1.2	0.2	1.4	-0.7	0.5
Station G:	Surface	Max	8.0	9.7	1.7	10.3	2.3
		Min	1.0	1.8	0.8	1.4	0.4
	Bottom	Max	9.0	12.5	3.5	11.0	2.0
		Min	4.0	6.2	2.2	6.2	2.2
Station A:	Surface	Max	11.1	10.5	-0.6	12.5	1.4
		Min	2.8	2.5	-0.3	2.6	-0.2
	Bottom	Max	8.3	9.8	1.5	10.6	2.3
		Min	-0.2	2.4	2.6	4.9	5.1
Station 19:	Surface	Max	11.1	9.3	-1.8	10.4	-0.7
		Min	1.9	2.2	0.3	2.4	0.5
	Bottom	Max	-1.0	-0.8	0.2	-1.9	-0.9
		Min	-1.2	-0.9	0.3	-2.8	-1.6

* Values are differences between the temperature extremes at the observation points at time of stability and the fresh-water temperatures, and are averages of two identical tests.

Table 2

Effect of Fox Point Barriers on Average Water Temperatures Throughout a Tidal Cycle

Location	Depth	Temperature Differences, °F: Base Test Temperature Difference*	Plan 1 Barrier Installed: Temperature Difference*	Plan 1 Barrier Installed: Effect of Plan 1	Plan 2 Barrier Installed: Temperature Difference*	Plan 2 Barrier Installed: Effect of Plan 2
South St. intake	Surface	5.6	8.1	2.5	9.4	3.8
	Intake	-0.5	1.9	2.4	0.7	1.2
Manchester St. intake	Surface	6.8	8.4	1.6	11.9	5.1
	Intake	2.1	10.0	7.9	10.6	8.5
Station A	Surface	6.9	6.4	-0.5	8.2	1.3
	Bottom	1.8	6.6	4.8	8.0	6.2
Station B	Surface	7.8	11.3	3.5	12.7	4.9
	Bottom	-0.8	1.4	2.2	0.6	1.4
Station G	Surface	3.8	5.4	1.6	5.2	1.4
	Bottom	6.8	9.7	2.9	9.8	3.0
Station 19	Surface	7.1	6.1	-1.0	6.5	-0.6
	Bottom	-1.1	-0.8	0.3	-2.4	-1.3
Entire area (after mixing at end of test)		4.2	7.2	3.0	7.6	3.4

* Values are differences between the average temperature over a tidal cycle at the observation point and the fresh-water temperatures, and are averages of two identical tests.

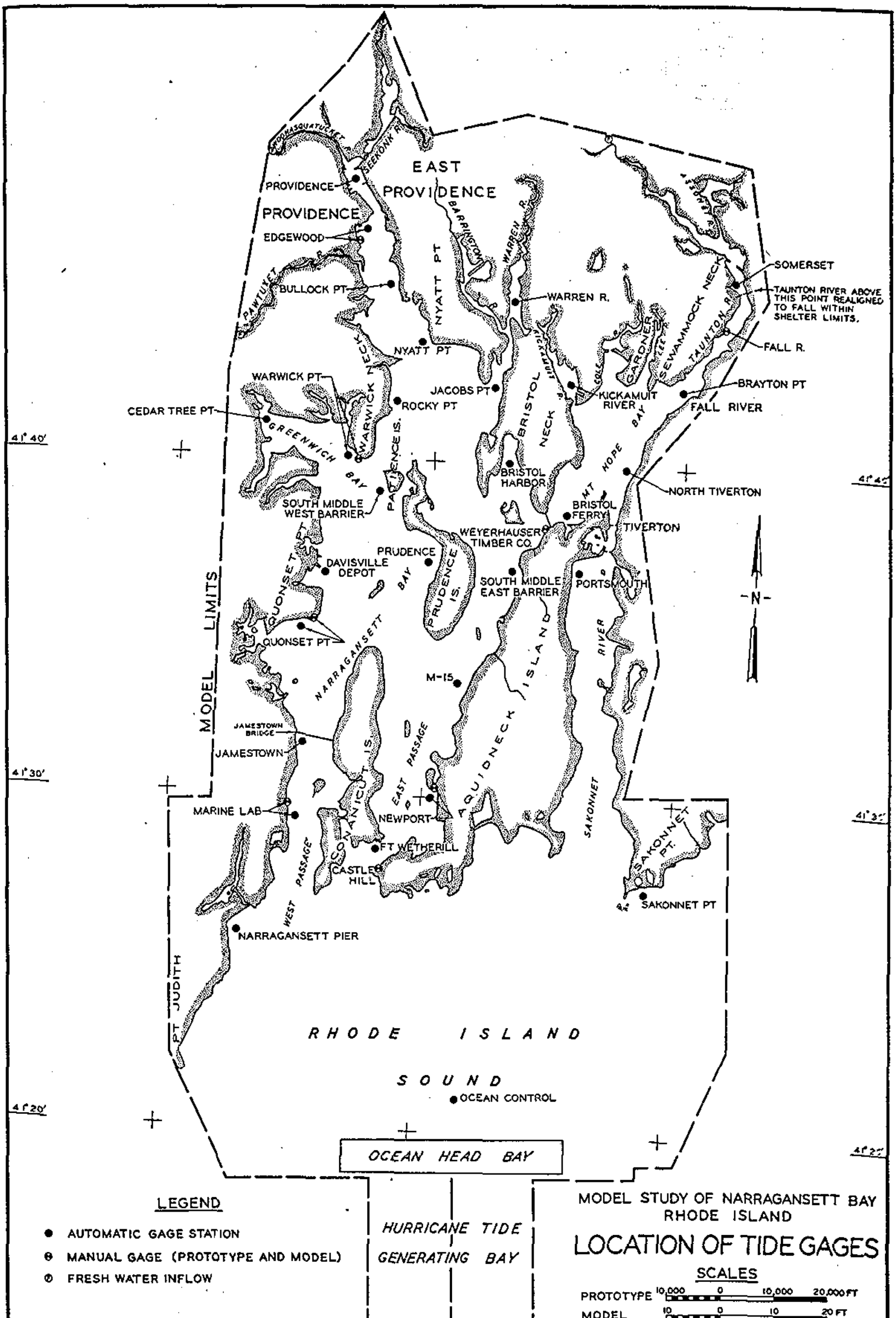

EAST PROVIDENCE
PROVIDENCE
PROVIDENCE
EDGEWOOD
BULLOCK PT
NYATT PT
NYATT PT
WARWICK PT
WARWICK NECK
CEDAR TREE PT
GREENWICH BAY
ROCKY PT
JACOBS PT
PATIENCE IS.
SOUTH MIDDLE WEST BARRIER
QUONSET PT
DAVISVILLE DEPOT
PRUDENCE
PRUDENCE IS.
PRUDENCE BAY
QUONSET PT
NARRAGANSETT
M-15
JAMESTOWN BRIDGE
JAMESTOWN
MARINE LAB
CONANICUT IS.
EAST PASSAGE
NEWPORT
FT WETHERILL
CASTLE HILL
WEST PASSAGE
NARRAGANSETT PIER
PT JUDITH
MODEL LIMITS
PAWTUXET R.
SEEKONK R.
BARRINGTON R.
WARREN R.
WARREN R.
BRISTOL NECK
BRISTOL HARBOR
KICKAMUIT RIVER
BRISTOL FERRY
WEYERHAUSER TIMBER CO.
SOUTH MIDDLE EAST BARRIER
PORTSMOUTH
AQUIDNECK ISLAND
MT HOPE BAY
SOMERSET
TAUNTON RIVER ABOVE THIS POINT REALIGNED TO FALL WITHIN SHELTER LIMITS.
SEWAMMOCK NECK
TAUNTON R.
GARDNER NECK
FALL R.
BRAYTON PT
FALL RIVER
NORTH TIVERTON
TIVERTON
SAKONNET RIVER
SAKONNET
SAKONNET PT.
SAKONNET PT
N
41° 40'
41° 30'
41° 20'
RHODE ISLAND SOUND
OCEAN CONTROL
OCEAN HEAD BAY
HURRICANE TIDE GENERATING BAY
LEGEND
AUTOMATIC GAGE STATION
MANUAL GAGE (PROTOTYPE AND MODEL)
FRESH WATER INFLOW
MODEL STUDY OF NARRAGANSETT BAY
RHODE ISLAND
LOCATION OF TIDE GAGES
SCALES
PROTOTYPE 10,000 0 10,000 20,000 FT
MODEL 10 0 10 20 FT

PLATE 1

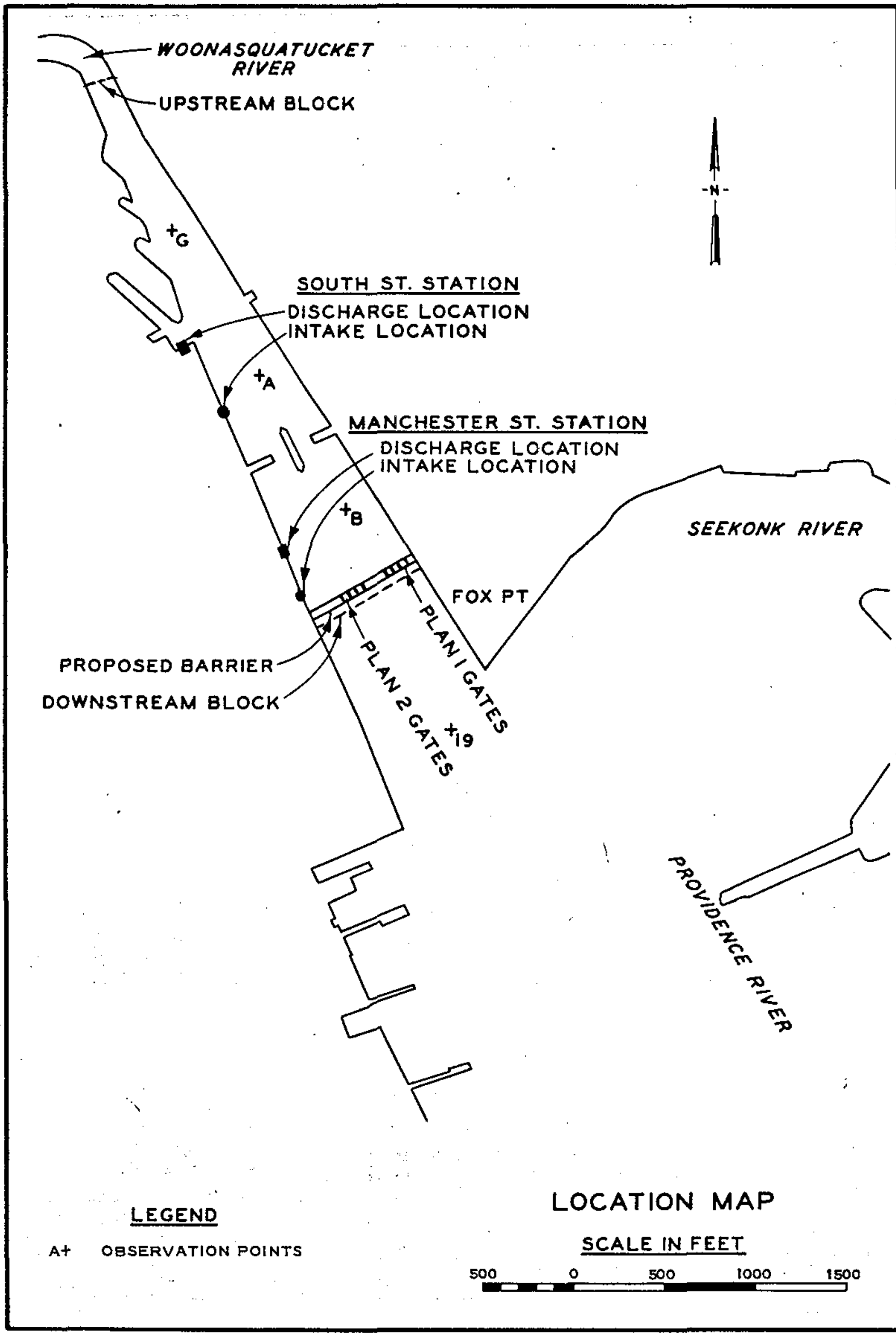
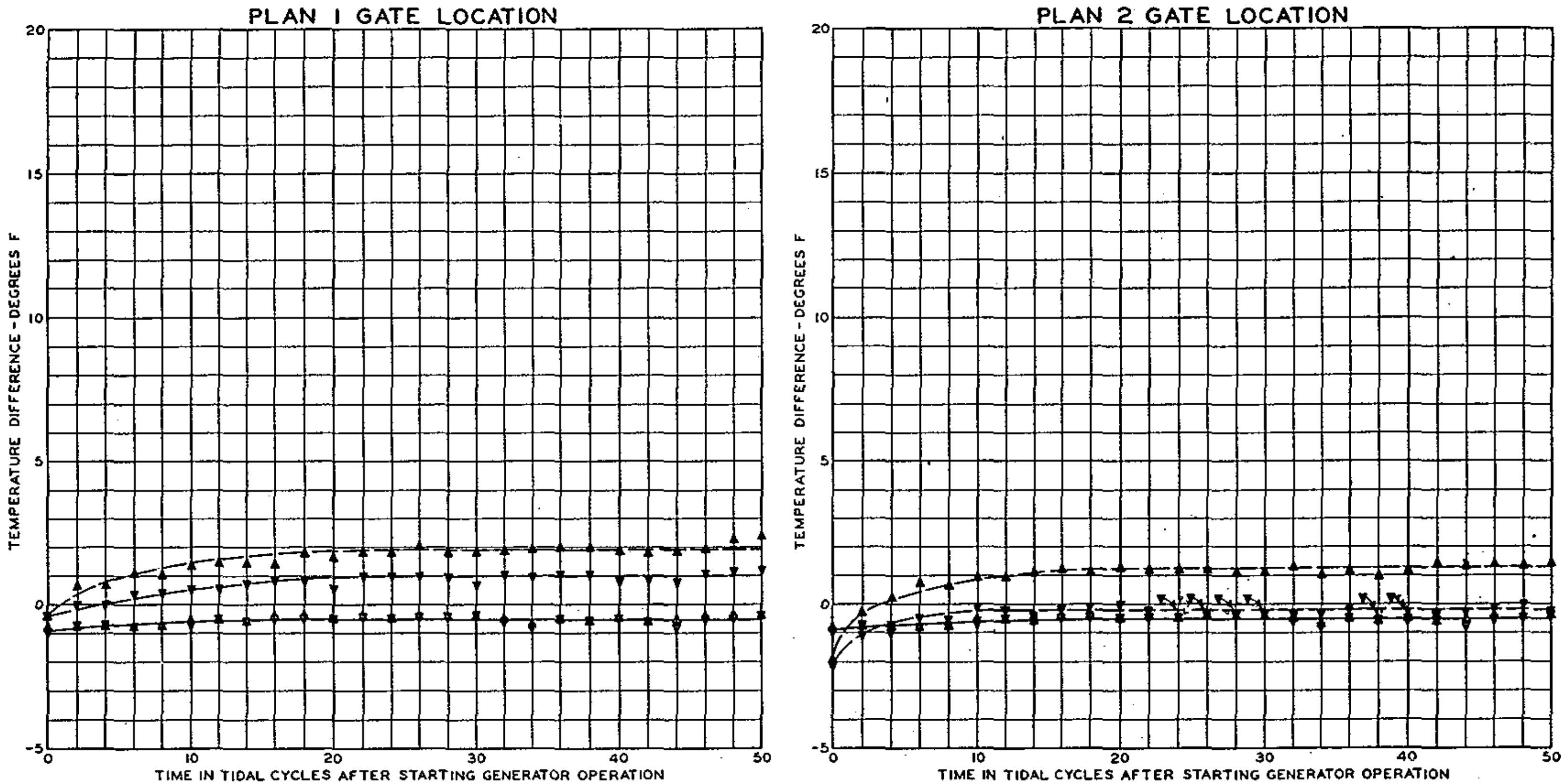

WOONASQUATUCKET RIVER
UPSTREAM BLOCK
+G
SOUTH ST. STATION
DISCHARGE LOCATION
INTAKE LOCATION
+A
MANCHESTER ST. STATION
DISCHARGE LOCATION
INTAKE LOCATION
+B
SEEKONK RIVER
FOX PT
PROPOSED BARRIER
DOWNSTREAM BLOCK
PLAN 1 GATES
PLAN 2 GATES
+19
PROVIDENCE RIVER
N
LEGEND
A+ OBSERVATION POINTS
LOCATION MAP
SCALE IN FEET
500 0 500 1000 1500

PLATE 2



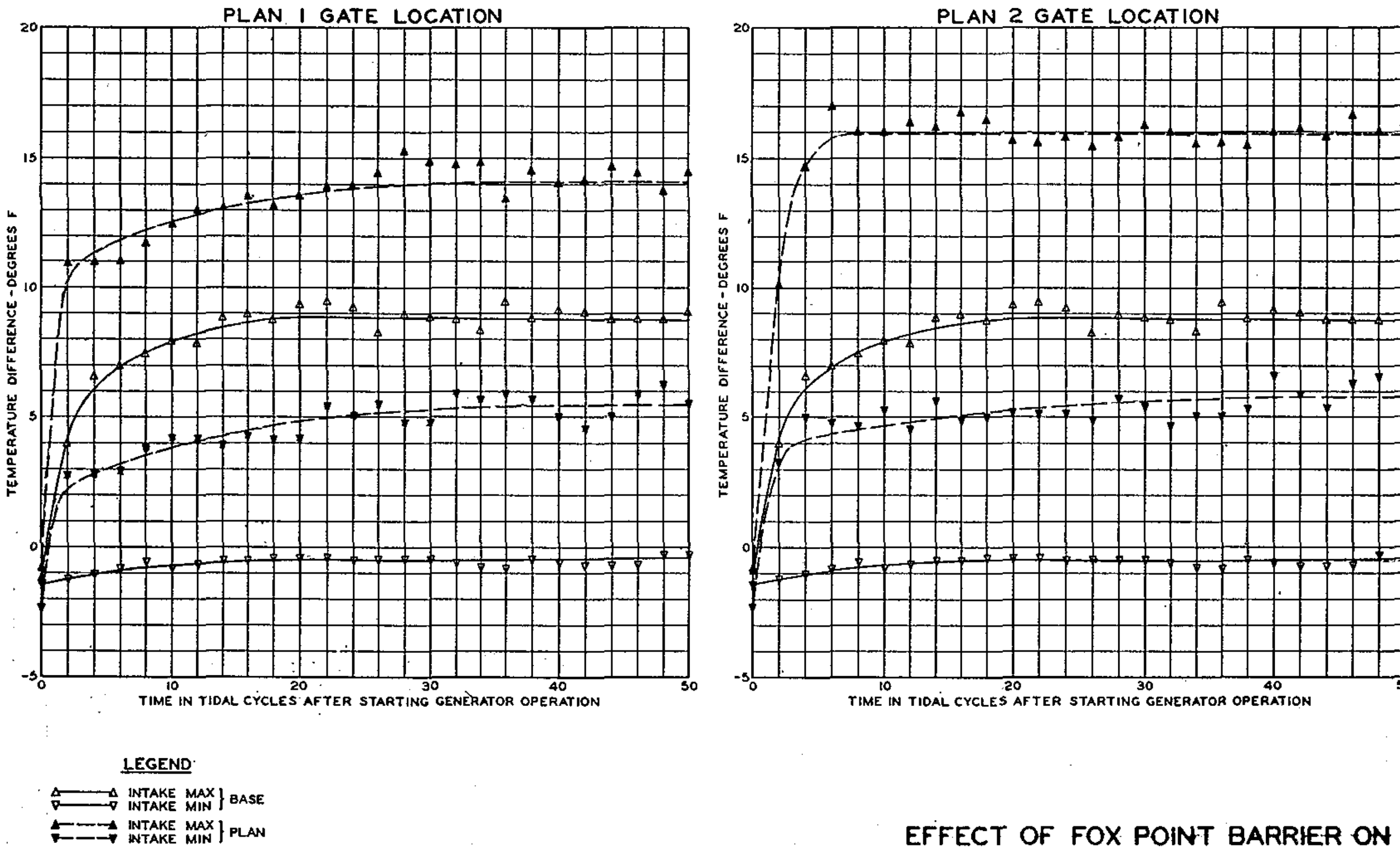
LEGEND

△——△ INTAKE MAX } BASE
▽——▽ INTAKE MIN } BASE
▲– – –▲ INTAKE MAX } PLAN
▼– – –▼ INTAKE MIN } PLAN

EFFECT OF FOX POINT BARRIER ON WATER TEMPERATURES

PLANS 1 AND 2

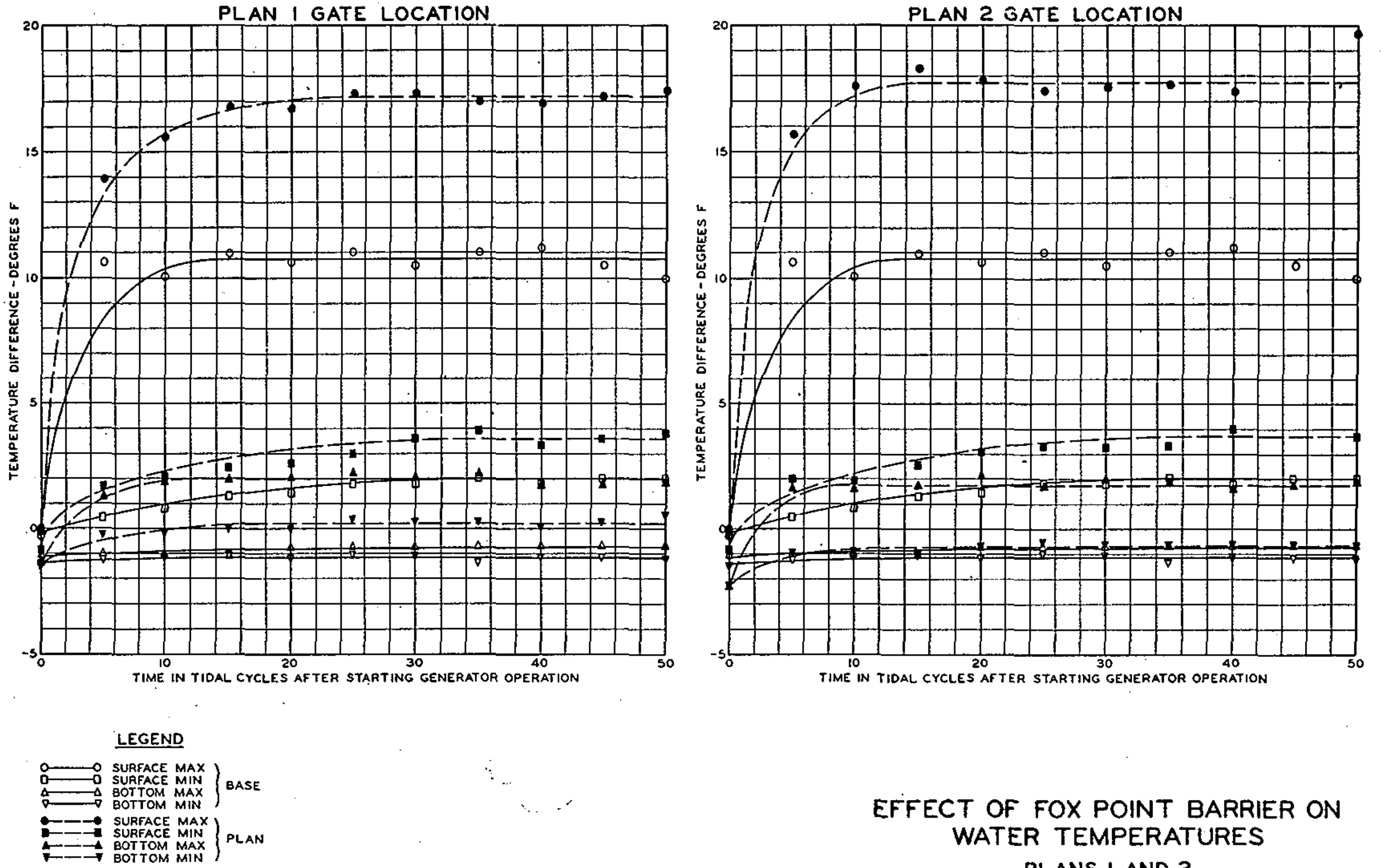
SOUTH STREET INTAKE



EFFECT OF FOX POINT BARRIER ON WATER TEMPERATURES

PLANS 1 AND 2

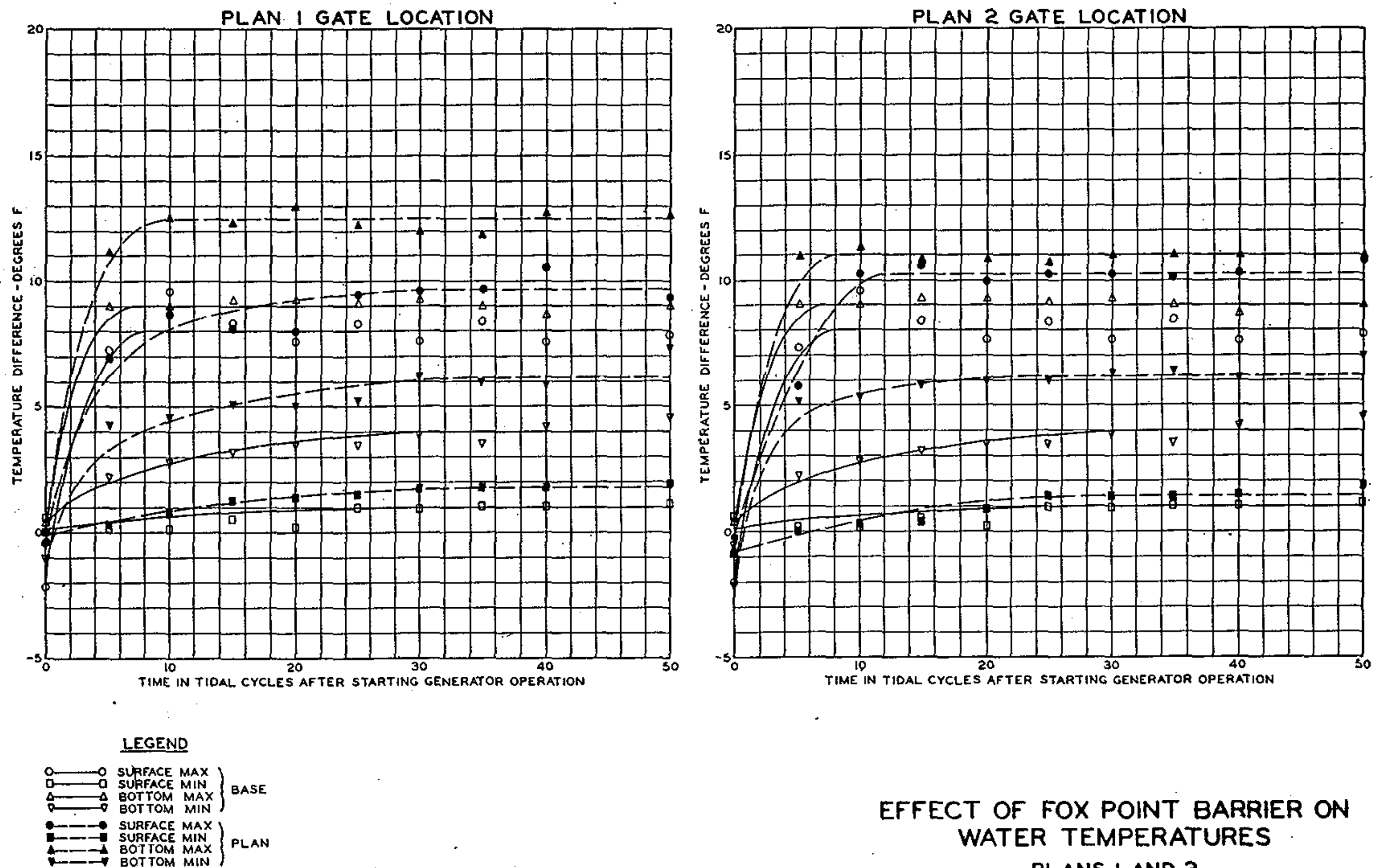
MANCHESTER STREET INTAKE



EFFECT OF FOX POINT BARRIER ON WATER TEMPERATURES

PLANS 1 AND 2

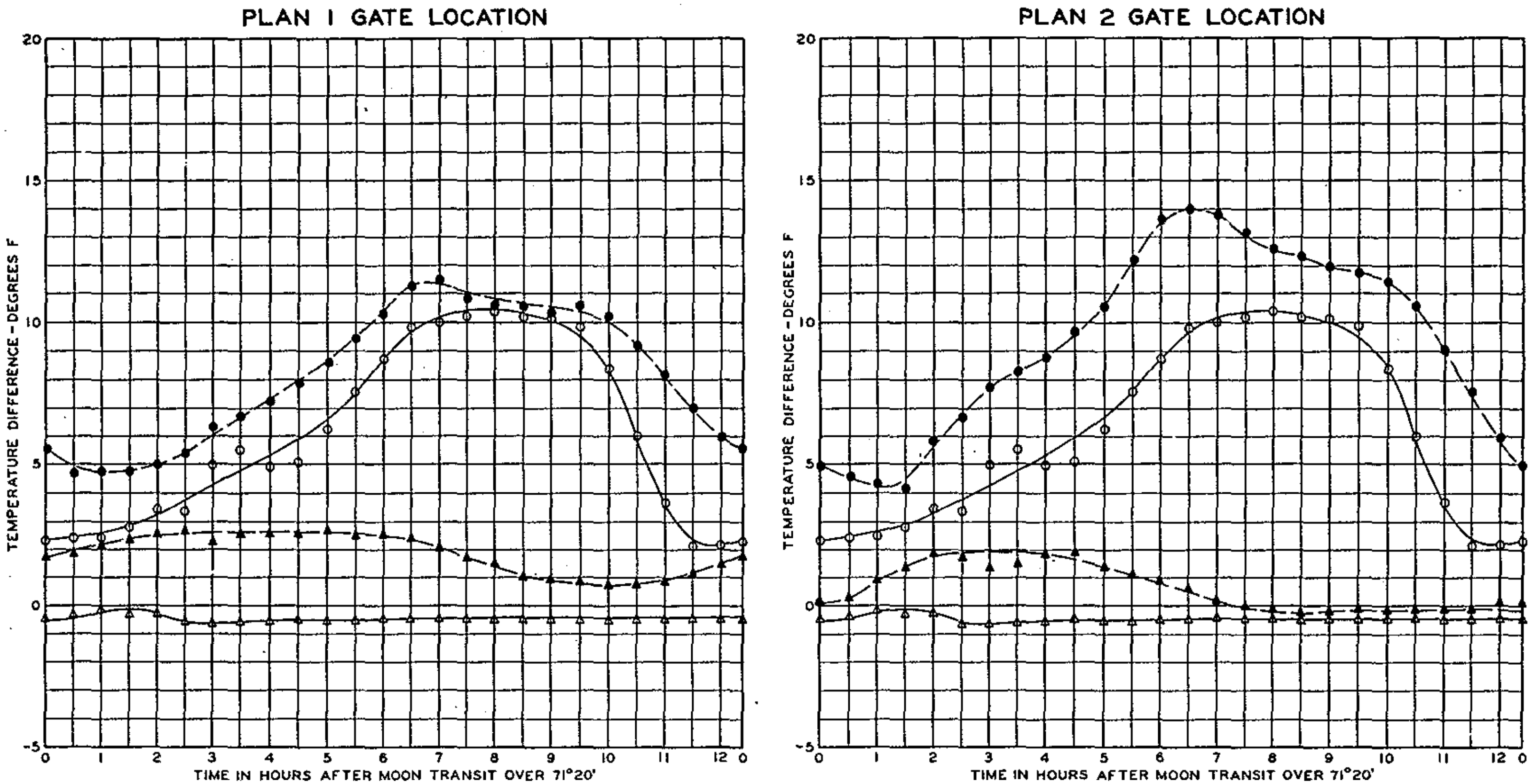
STATION B



EFFECT OF FOX POINT BARRIER ON
WATER TEMPERATURES

PLANS 1 AND 2

STATION G



LEGEND

- SURFACE, INTAKE } BASE
- SURFACE, INTAKE } PLAN

NOTE: DATA OBTAINED AFTER TEMPERATURES AT LOCATIONS B AND G WERE OBSERVED TO BE STABLE.

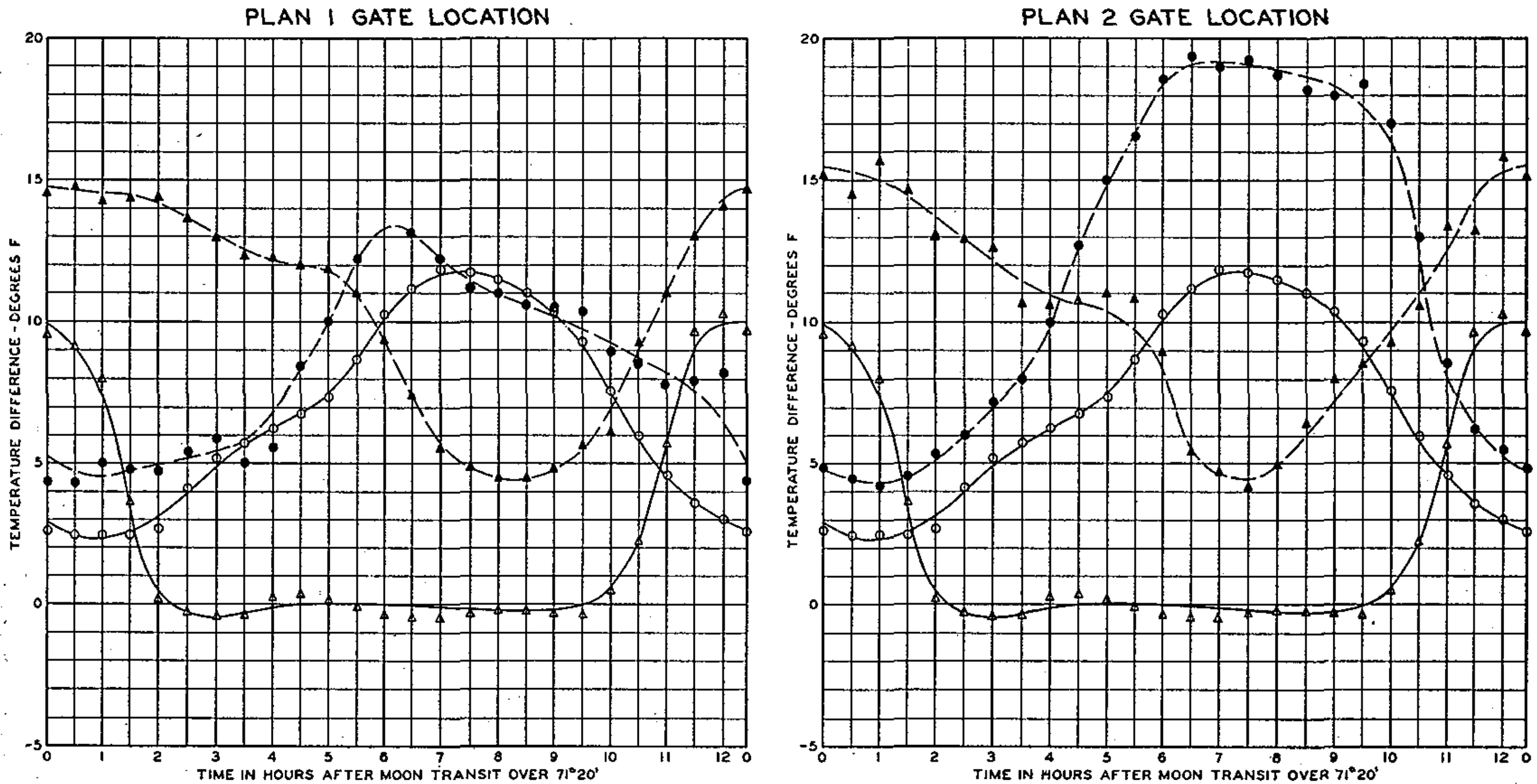
EFFECT OF FOX POINT BARRIER ON WATER TEMPERATURES THROUGHOUT A TIDAL CYCLE

PLANS 1 AND 2

SOUTH STREET INTAKE

PLATE 7

PLATE 8



LEGEND

SURFACE, INTAKE } BASE
SURFACE, INTAKE } PLAN

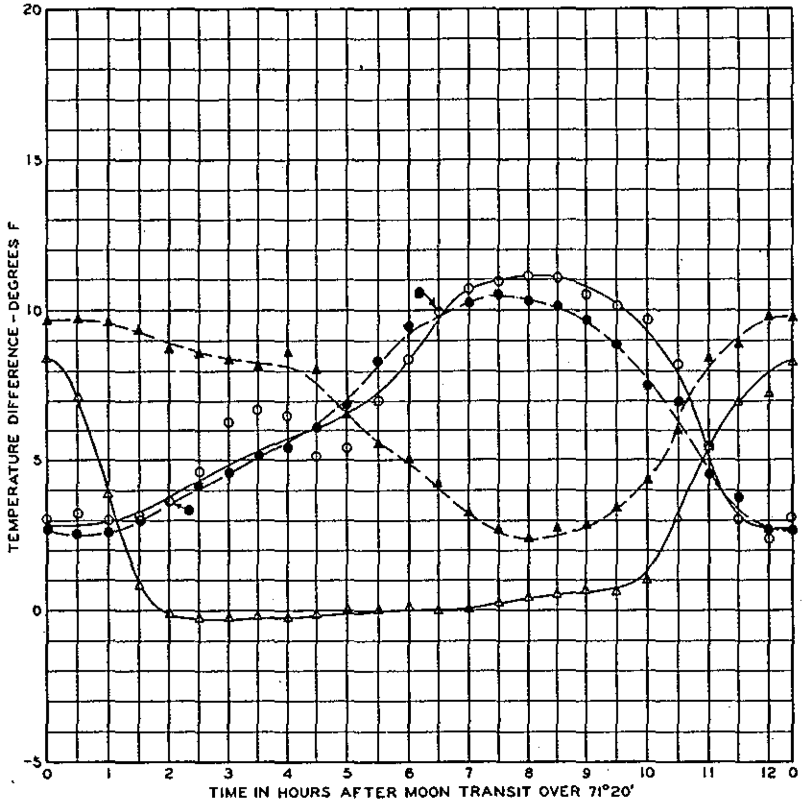
NOTE: DATA OBTAINED AFTER TEMPERATURES AT LOCATIONS B AND G WERE OBSERVED TO BE STABLE.

EFFECT OF FOX POINT BARRIER ON WATER TEMPERATURES THROUGHOUT A TIDAL CYCLE

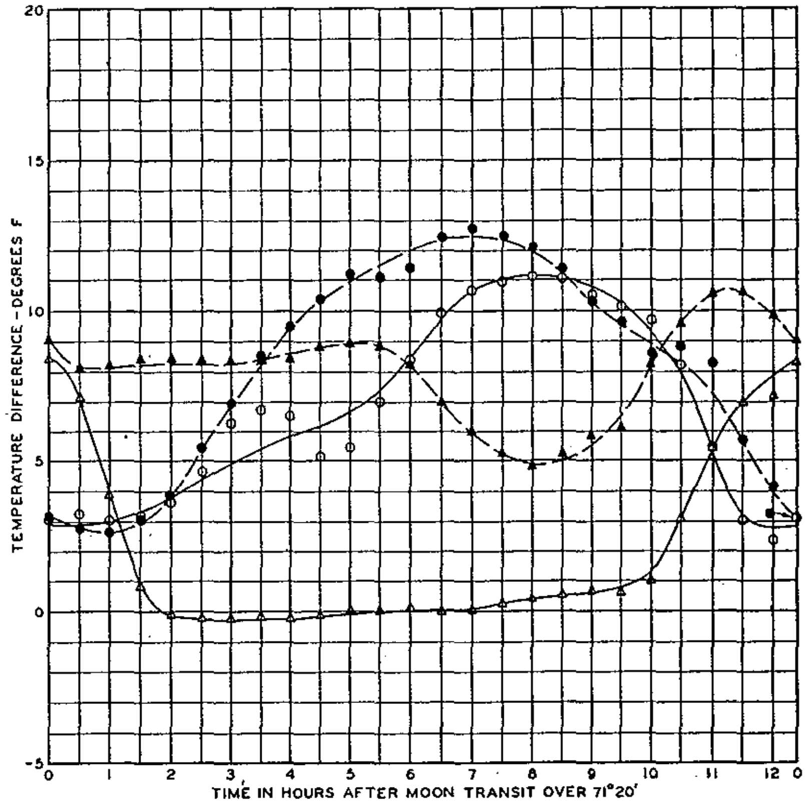
PLANS 1 AND 2

MANCHESTER STREET INTAKE

PLAN 1 GATE LOCATION



PLAN 2 GATE LOCATION



LEGEND

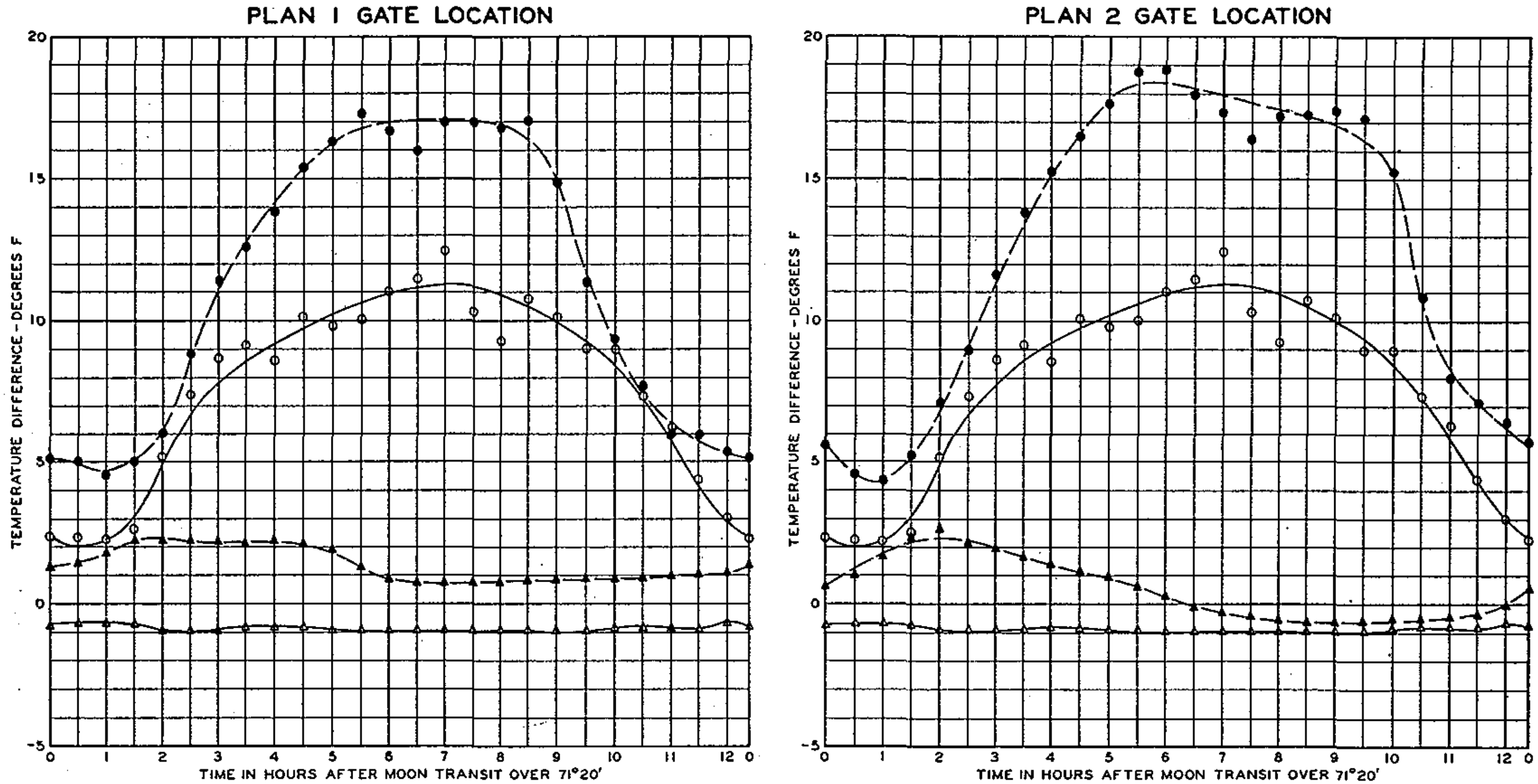
- ○——○ SURFACE, △——△ BOTTOM } BASE
- ●– – –● SURFACE, ▲– – –▲ BOTTOM } PLAN

NOTE: DATA OBTAINED AFTER TEMPERATURES AT LOCATIONS B AND G WERE OBSERVED TO BE STABLE.

EFFECT OF FOX POINT BARRIER ON WATER TEMPERATURES THROUGHOUT A TIDAL CYCLE

PLANS 1 AND 2

STATION A



LEGEND

SURFACE } BASE
BOTTOM

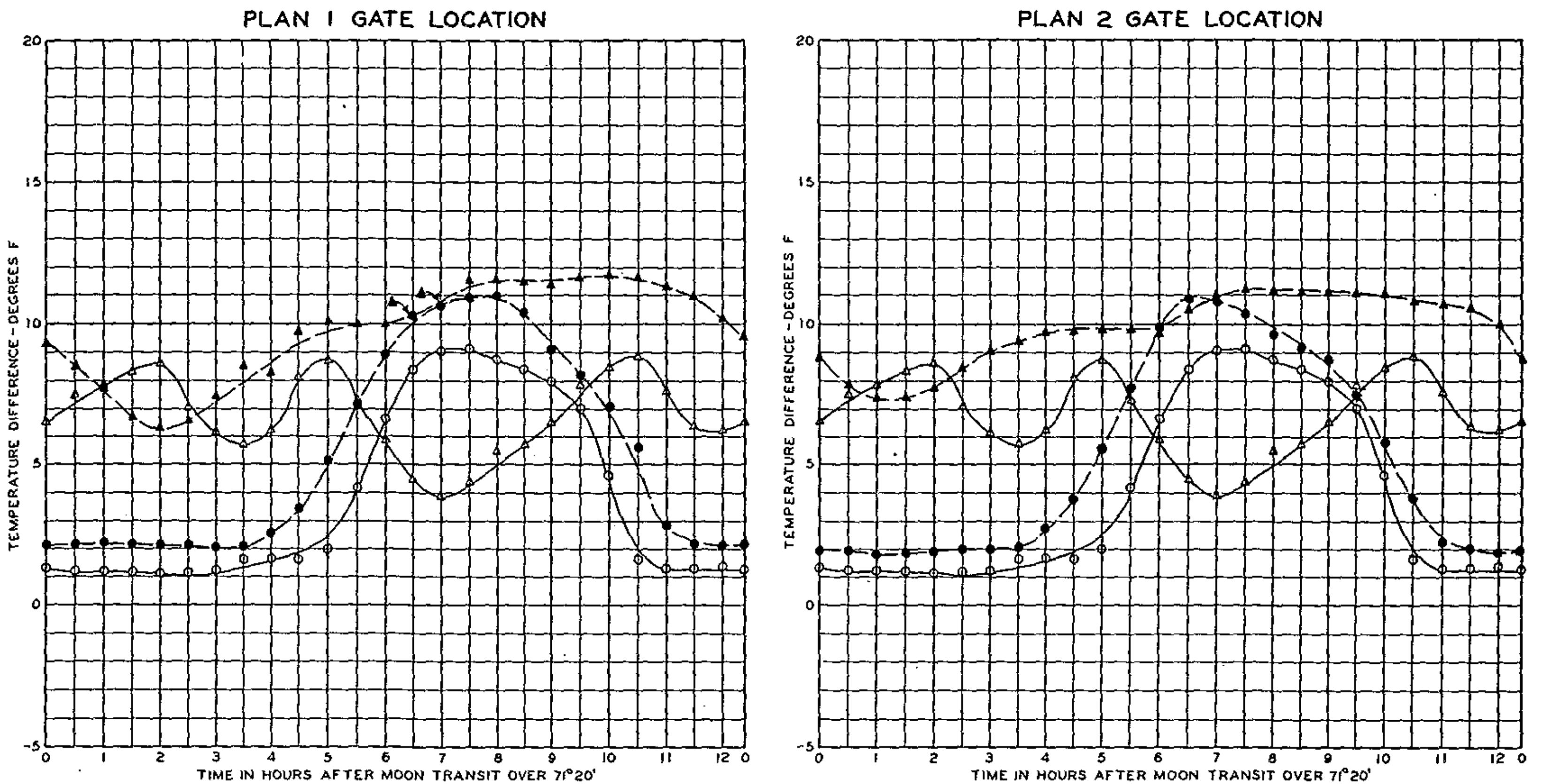
SURFACE } PLAN
BOTTOM

NOTE: DATA OBTAINED AFTER TEMPERATURES AT LOCATIONS B AND G WERE OBSERVED TO BE STABLE.

EFFECT OF FOX POINT BARRIER ON WATER TEMPERATURES THROUGHOUT A TIDAL CYCLE

PLANS 1 AND 2

STATION B



LEGEND

SURFACE } BASE
BOTTOM

SURFACE } PLAN
BOTTOM

NOTE: DATA OBTAINED AFTER TEMPERATURES AT LOCATIONS B AND G WERE OBSERVED TO BE STABLE.

EFFECT OF FOX POINT BARRIER ON WATER TEMPERATURES THROUGHOUT A TIDAL CYCLE

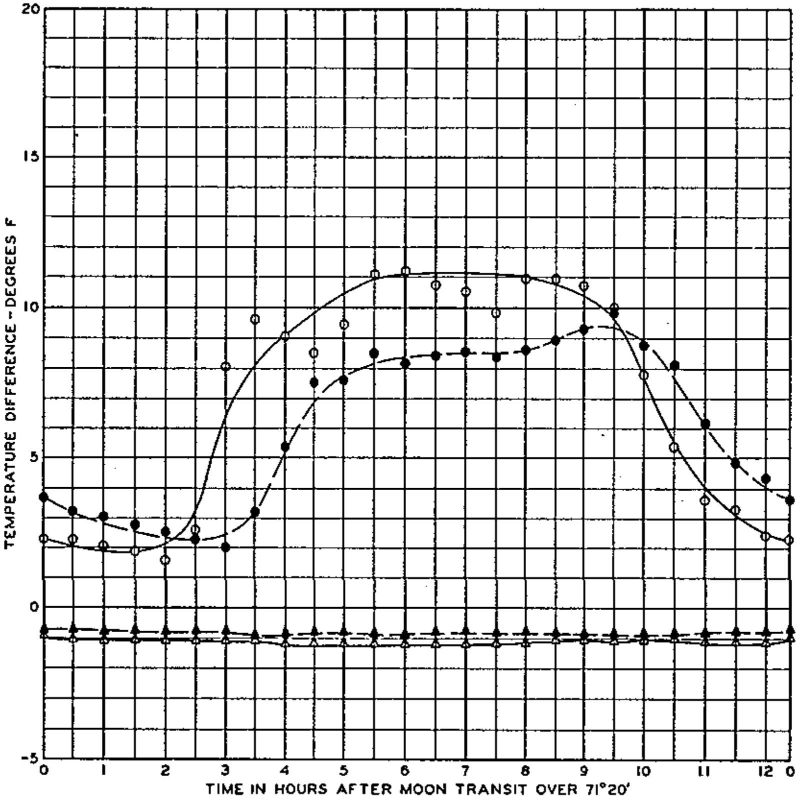
PLANS 1 AND 2

STATION G

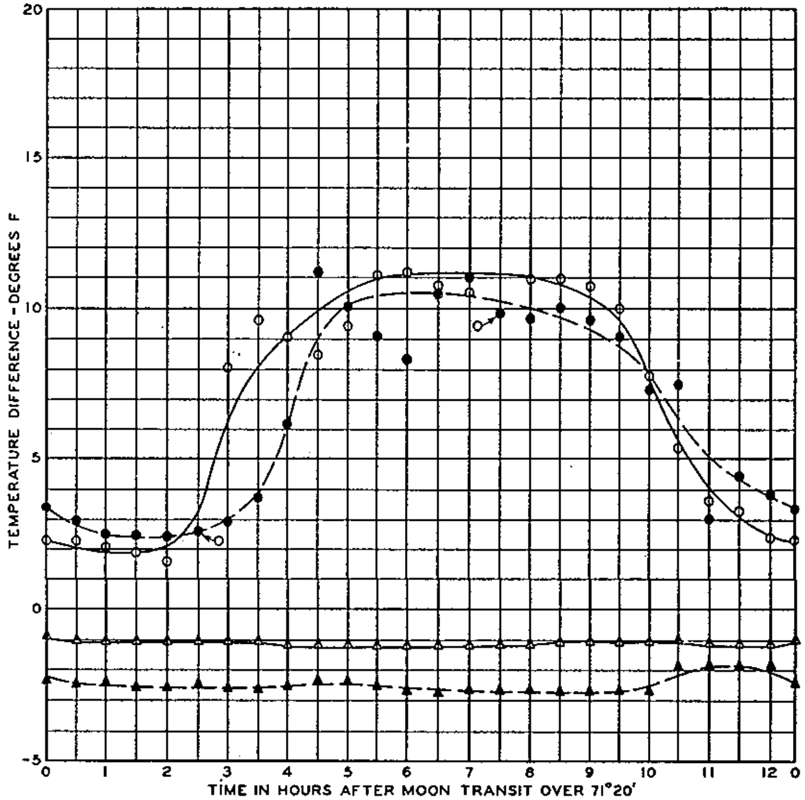
PLATE 11

PLATE 12

PLAN I GATE LOCATION



PLAN 2 GATE LOCATION



LEGEND

SURFACE } BASE
BOTTOM

SURFACE } PLAN
BOTTOM

NOTE: DATA OBTAINED AFTER TEMPERATURES AT LOCATIONS B AND G WERE OBSERVED TO BE STABLE.

EFFECT OF FOX POINT BARRIER ON WATER TEMPERATURES THROUGHOUT A TIDAL CYCLE

PLANS I AND 2

STATION 19